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# Insertion Device Activities for NSLS-II

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## Abstract

National Synchrotron Light Source –II (NSLS-II) will be a medium energy storage ring of 3GeV electron beam energy with sub-nm.rad horizontal emittance and top-off capability at 500mA. Damping wigglers will be used not only to reduce the beam emittance but also used as broadband sources for users. Cryo-Permanent Magnet Undulators (CPMUs) are considered for hard X-ray linear device, and permanent magnet based elliptically polarized undulators (EPUs) for variable polarization devices for soft X-ray. 6T superconducting wiggler with minimal fan angle will be installed in the second phase as well as quasi-periodic EPU for VUV and possibly high-temperature superconducting undulator. R&D plans have been established to pursue the performance enhancement of the baseline devices and to design new types of insertion devices. A new insertion device development laboratory will also be established.

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## I. INTRODUCTION

National Synchrotron Light Source –II (NSLS-II) will provide the electron beam with sub-nm.rad horizontal emittance and 500mA of electron beam current with top-off capability by 2013. 1.8T damping wigglers will be used for both emittance reduction purpose and broadband user hard X-ray source albeit with large power density to be handled. The bending magnet field is chosen relatively weak (0.4T) compared to other light sources in order to minimize the dispersion. As a result, the critical energy of bending magnets is too low for NSLS-I bending-magnet hard X-ray users. Three pole wiggler will be installed at the end of dispersive section to accommodate those users at the expense of small beam emittance increase. The main hard X-ray undulator source will be cryogenic permanent magnet undulator (CPMU) [1], and out-of-vacuum elliptically polarized undulator (EPU) will cover soft X-ray regions. Table 1 shows the list of baseline insertion devices planned for the first phase of the operation of the ring.

Phase II insertion devices include, 6T superconducting wiggler (SCW), VUV quasi-period EPU, and possibly superconducting undulator (SCU). R&D plans are established to ensure the performance goals of various devices are achieved. In section II, we discuss the preliminary designs of the baseline devices as well as the phase-II devices. Issues of cold measurement for CPMUs is discussed in in section III . Section IV is devoted to the future R&D plans and establishment of new insertion device laboratory.



## II. INSERTION DEVICES PLANNED FOR NSLS-II

### 2-1. Planar Hybrid Cryo-Permanent Magnet In-Vacuum Undulator

NdFeB type permanent magnet which is most commonly used in insertion devices has a negative thermal coefficient of remanent field ( $B_r$ ) and also of intrinsic coercivity ( $H_{c_j}$ ). Therefore, one can expect higher field and higher radiation resistance simply by cooling the magnet array to lower temperature. Typical value of the former is  $-0.1\%/^{\circ}\text{K}@20^{\circ}\text{C}$  and the latter  $-0.5\%/^{\circ}\text{K}@20^{\circ}\text{C}$ . The latter fact is considered important for the medium energy ring with top-off capability due to the increased number of lost electrons. NdFeB exhibits a spin orientation below 150K and its  $B_r$  starts decreasing as the temperature goes lower) [2]. Recent reports [3] show the peak performance of magnetic circuits was obtained in slightly lower temperature than that from single magnet. Therefore the cooling system should be able to handle at least 120K operation.

The baseline design of U19 CPMU is based on the X-25 MGU [4] which was installed in NSLS X-ray ring in December, 2005. Besides providing higher field than pure permanent magnet (PPM) device, another advantage of hybrid structure for CPMU configuration is that magnets have magnetization in the longitudinal direction. A NdFeB magnet can have negative thermal expansion coefficients in the direction perpendicular to the easy axis, which results in greater mechanical stress with temperature gradient for PPM structure.

### 2-2. EPU design

The most popular design, based on PM technology, is the Advanced Planar Polarized Light Emitter (APPLE) type [5]. It has been popular because it can generate all the possible polarization states with the minimum number of magnets. However, it also has a few

69 deficiencies. Strong multipole components inherent to the design would reduce the dynamic  
70 aperture of the machine. No separation of vertical and horizontal field components from  
71 different magnetic arrays would also complicate magnetic shimming. Heretofore, no  
72 shimming method valid for all the polarization states has been found. There is an alternative  
73 design proposed for HiSOR by SPring-8 [6]. It separates the magnets for horizontal and  
74 vertical field, for ease of tuning as well as more moderate skew multipoles, at the expense of  
75 weaker achievable horizontal field. Detailed tracking studies will be carried out to decide  
76 which type of device is appropriate for NSLS-II. Another concern for NSLS-II EPU is the  
77 possible demagnetization of the permanent magnets by the use of the APS-style narrow gap  
78 vacuum chamber [7]. Improvements to the vacuum chamber design will be investigated in  
79 order to minimize the source of radiation at the extremities of the chamber.

80

### 81 2-3. Damping Wiggler

82 NSLS-II damping wiggler (DW) is used not only for electron beam  
83 emittance reduction but also for broad-band radiation source. Since there is a  
84 provision for canting of two devices, it is important to minimize the fan angle of the  
85 radiation for easy separation. The first version described in the CDR employs  
86 standard hybrid structure of the period length of 100mm with permendur poles and  
87 NdFeB magnets. Various new requirements have called for new design.

88 1) New requirements from absorber heatload demands further reduction of the fan  
89 angle from 2.8 mrad for CDR-DW.

90 2) Damping effect of the device which is proportional to the integral of  $B_y^2$  of the  
91 CDR-DW has only 90% of that of the ideal device.

92 Therefore, a new 80mm period hybrid device with side magnets has been  
93 designed to supplement these deficiencies. The magnetic gap has been decreased  
94 from 15mm to 12mm to obtain 103% of the damping effect of the ideal device

95 without increasing the peak field. The fan angle has been reduced from 2.8mrad to  
96 2.3mrad.

97 The effect of longitudinal higher harmonics and transverse roll-off of the  
98 vertical field component on the dynamic aperture has been studied [8]. It shows that  
99 the vertical dynamic aperture will be reduced by approximately 50% if the harmonics  
100 up to the 7<sup>th</sup> are included in the analysis.

101

#### 102 2-4. Three pole wiggler

103 NSLS-II DW will be an excellent source for broadband hard X-ray users.  
104 However, the number of available beam lines is limited and some users prefer to have  
105 radiation with lower angular power density for their optics. Three pole wiggler will  
106 be utilized to accommodate this type of user. It will be installed before the second  
107 bending magnet in the dispersive section in order not to modify the vacuum chamber  
108 shape to incorporate the device. Main design requirements are the followings:

- 109 1) More than 2 mrad of fan angle of the radiation from the field of at least 1 Tesla.  
110 2) Minimize the emittance degradation by suppressing the peak field of side poles  
111 while maintaining the closed bump.

112

#### 113 2-5. Phase II devices

114 Superconducting insertion devices with superior performance to PM  
115 devices are planned for the second phase of the development as well as  
116 unconventional PM devices. 60mm period / 6T SCW requires more than 1300 A /  
117 mm<sup>2</sup> for 15mm magnetic gap. Artificial Pinning Center (APC) NbTi may be used for  
118 this device if the result of R&D will satisfy the requirements. Due to the high field  
119 condition, the use of Nb<sup>3</sup>Sn wire will be pursued simultaneously. Low temperature  
120 SCU has intrinsic difficulty due to the proximity of cold mass to various heat sources.



121 Medium temperature superconductor such as MgB<sub>2</sub> ( $T_{cr} = 39\text{K}$  in self field) and a  
122 variety of high temperature conductors (YBCO, GdBCO, etc.) which are developing  
123 rapidly will be a promising candidate for realistic storage-ring SCU. As for other  
124 PM device, a long period QEPU has been proposed. However dynamic field integral  
125 effect is proportional to the period squared, and with combination of intrinsic  
126 multipole components of EPU device, careful design and trackings will be required.

127

### 128 **III. DEVELOPMENT OF COLD MEASUREMENT SYSTEM**

#### 129 3-1. Field measurement requirement

130

131 Cryogenic insertion device, whether CPMU at 130K or SCU at 4K, has  
132 to be field-measured and corrected to satisfy beam dynamics conditions. It is  
133 preferable that the field measurement can be conducted in high vacuum with  
134 temperature controlled environment. For field mapping system, monitoring the  
135 precise location and temperature of Hall probes is essential. The variation of the  
136 integrating area due to temperature change must be compensated to obtain accurate  
137 integrated field measurement. International efforts are aimed to establish a reliable  
138 cold insertion device measurement system [3].

#### 139 3-2. CPMU vacuum chamber design

140 Our current line of thinking is that the cold measurement should be able to  
141 be conducted without removing the vacuum chamber of the in-vacuum device.  
142 Therefore the vacuum chamber must have continuous opening on one side similar to  
143 MGU-X25 for NSLS. Detailed design efforts are being made for this subject.

### 144 **IV. R&D ACTIVITIES AND NEW ID MEASUREMENT LAB**

145           Vertical test facility is in operation with boiling LHe pool. It is planned  
146 to be connected to a closed circuit He gas refrigerator able to adjust the device  
147 temperature between 4K and 200K. Small prototype YBCO tape based SCU and  
148 MgB2 thick film conductor patterns will be tested in the near future.

149           Praseodymium iron boron (PrFeB) magnet continually increases its  
150 remanent field as the temperature is decreased. This technique will offer significantly  
151 higher magnetic field as well a lower temperature regime where distortion produced  
152 by thermal heat loads will be minimized. We also investigate the use of dysprosium  
153 poles for hybrid magnet structures which could potentially have a saturation level of  
154 over three Tesla which can dramatically increase CPMU performance over the  
155 currently used materials such as vanadium-permendur.

## 156   V.       SUMMARY

157           Due to the strict beam stability requirement and sensitivity of medium  
158 energy low emittance electron beam, all the insertion devices for NSLS-II will have to  
159 comply higher standard than many existing devices. Rigorous R&D will ensure the  
160 success of this project.

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184 **Table 1** Planned Insertion Devices for NSLS-II (Phase-I)

Insertion Device	CPMU	EPU	DW	3 Pole Wiggler
Magnetic Flux Density, $B_{peak}[T]$	1.2	1.03 (lin) 0.64/0.64 (helical)	1.8	1.1
Total Length [m]	3	2 x 2	3.5 x 2	0.3
Minimum Magnetic Gap [mm]	5.0	10.0	12.0	32.0
Period Length, $\lambda_u$ [mm]	19	45	80	-
Wiggler Characteristic Energy, $E_c$ [KeV]	-	-	10.8	6.8
Photon Energy Range [KeV]	1.5 - 20	0.18 - 7	>0.01 - 100	>0.01 - 40
Maximum K	2.03 (eff)	4.33 (lin) 2.69 (heli)	13.6 (eff)	-
Max Total Power [kW]	11.2	12.09	64.6	0.34

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